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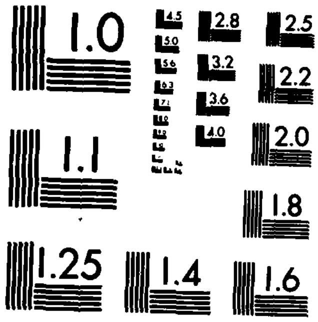
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by

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ABSTRACT

The geometrical relationships of Pioneer 11 to Uranus and Voyager 2 during 1985-86 are summarized, with special attention to conditions during Voyager 2's encounter with Uranus on 24 January 1986. It is shown that Pioneer 11 will be able to provide valuable observations of the solar wind, the magnetic field, and energetic particle intensity in the nearby interplanetary medium before, during, and after that encounter. All of these quantities are significant in determining the state of Uranus' magnetosphere and fluctuations thereof.

1. Introduction

Pioneer 11 will not pass close enough to Uranus to permit significant observations of the planet itself. Nonetheless, its geometrical relationships to Uranus and Voyager 2 in 1985-86 are favorable:

(a) For correlative studies with Voyager 2 on the solar wind, the interplanetary magnetic field and energetic particles; and especially

(b) For support of the 24 January 1986 encounter of Voyager 2 with Uranus by monitoring these physical conditions before, during, and after that encounter. Such interplanetary quantities are of importance in determining the state of Uranus' magnetosphere.

This memorandum offers a preliminary study of the geometrical relationships of the three objects and suggests some significant scientific opportunities. Sources of data and nomenclature are listed in Appendix I.

2. **Pioneer 11**

Table 1
(Reference (b))

0^h ET Date	r	λ	β
1/1/85	17.557	243°85	16°55
2/1	17.757	244.40	16.56
3/1	17.939	244.89	16.57
4/1	18.141	245.42	16.58
5/1	18.337	245.93	16.59
6/1	18.540	246.44	16.60
7/1	18.736	246.92	16.61
8/1	18.941	247.40	16.62
9/1	19.144	247.89	16.62
10/1	19.343	248.34	16.62
11/1	19.548	248.80	16.63
12/1	19.746	249.23	16.63
1/1/86	19.952	249.67	16.63
1/24/86	20.105	249.99	16.63
2/1	20.158	250.10	16.63
3/1	20.345	250.48	16.63
4/1	20.551	250.90	16.63
5/1	20.751	251.29	16.62
6/1	20.959	251.69	16.62
7/1	21.159	252.06	16.62

In January 1986 the pole of the orbital plane of Pioneer 11 is at

$$\theta = 16^\circ.629$$
$$\lambda = 69.765$$

Thus, the inclination of the orbital plane to the ecliptic is $16^\circ.629$. The maximum northerly latitude of Pioneer 11 will occur on 1/4/86.

Pioneer 11 will not cross Uranus' magnetotail within its useful lifetime.

3. <u>Uranus</u>

Table 2
(interpolated from reference (a))

0^h ET Date	r	λ	β
1/1/85	19.052	253°63	0°0028
7/1/85	19.085	255.78	-0.0263
1/1/86	19.118	257.96	-0.0556
1/24/86	19.122	258.23	-0.0593
7/1/86	19.151	260.10	-0.0844

Uranus' orbit is inclined at 0°773 to the ecliptic. Its mean annual motion in longitude is 4°285.

4. Voyager 2

Table 3
(Reference (c))

0^h ET Date	r	λ	β
1/1/85	15.917	250°00	0°323
2/2	16.171	250.80	0.286
3/2	16.395	251.48	0.255
4/1	16.637	252.18	0.222
5/1	16.879	252.87	0.190
6/2	17.140	253.58	0.157
7/2	17.386	254.23	0.127
8/1	17.632	254.86	0.098
9/2	17.897	255.51	0.068
10/2	18.147	256.10	0.040
11/1	18.397	256.68	0.013
12/1	18.649	257.24	-0.013
1/2/86	18.918	257.83	-0.040
1/24/86	19.104	258.22	-0.059
2/1	19.165	258.41	-0.054
3/1	19.366	259.15	-0.023
4/2	19.600	259.96	0.010
5/2	19.820	260.71	0.042

Following Voyager 2's close encounter with Uranus, its $d\lambda/dt \sim 9$ degrees per year. Hence, it will not make a second crossing of the magnetotail of Uranus within its useful lifetime.

5. Geometrical Relationships

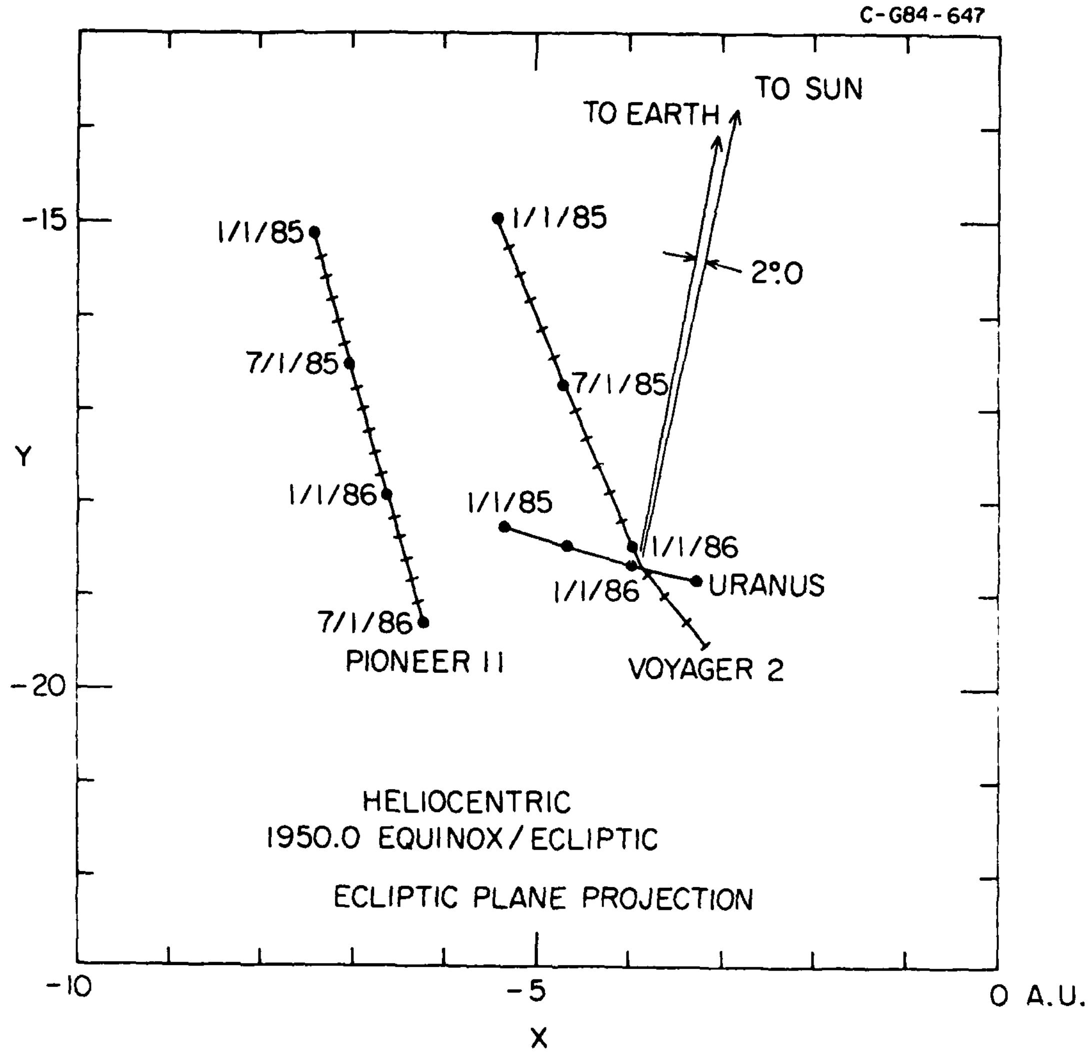
Figure 1 shows the trajectories of Pioneer 11, Voyager 2, and Uranus as projected on the ecliptic plane. The latter two bodies are close to the ecliptic plane and hence their relationship is well represented by this diagram. However, Pioneer 11 is substantially north of this plane, having a z-coordinate of 5.753 AU on 1/24/86 (cf. Table 1). In fact, Pioneer 11's closest approach to Uranus is 6.18 AU in mid-1985. Further details are given in Table 4.

Table 4

$\vec{r}_{PU}$

Date	r	λ	θ
1/1/85	6.265	302°84	142°92
7/1/85	6.184	319.85	150.17
1/1/86	6.360	343.80	154.24
1/24/86	6.400	347.04	154.43
7/1/86	6.770	8.20	153.88

A further significant relationship of Pioneer 11 to Uranus is evident from Table 5.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TO SUN
TO EARTH
2°.0
1/1/85
7/1/85
1/1/86
7/1/86
PIONEER II
1/1/85
7/1/85
1/1/86
VOYAGER 2
1/1/85
1/1/86
URANUS
HELIOCENTRIC
1950.0 EQUINOX/ECLIPTIC
ECLIPTIC PLANE PROJECTION
-15
-20
Y
-10
-5
0 A.U.
X

Figure 1

Table 5

Date	λ_U	λ_P	$\lambda_U - \lambda_P$	Solar Corotation Lag
1/1/85	253°630	243°846	9°784	16.56 hr.
7/1/85	255.782	246.920	8.862	15.00
1/1/86	257.961	249.670	8.291	14.03
1/24/86	258.233	249.990	8.243	13.95
7/1/86	260.097	252.065	8.032	13.59

6. Scientific Opportunities

The foregoing provides the basis for suggesting that Pioneer 11 can provide valuable correlative observations before, during, and after the encounter of Voyager 2 with Uranus, viz.:

(a) Solar wind velocity, density, and temperature;

(b) Interplanetary magnetic field vector;

(c) Occurrence of interplanetary shocks;

(d) Intensity and energy spectra of solar and shock-accelerated energetic electrons and protons; and

(e) Cosmic-ray intensity

-- all as a function of time.

Some or all of these quantities are of importance in understanding the magnetosphere of Uranus (Appendix II) and the temporal variations thereof. Measurements <u>during</u> the period of the Voyager 2 encounter will be of special value in order to monitor changes in interplanetary conditions.

7. Practical Considerations

(a) Presumably each of the 64-meter antennae of the Deep Space Network will be fully committed during December 1985 -- February 1986 to Voyager 2 whenever it is above the station's horizon, with the exception of a few days around 10 December 1985 at the time of conjunction.

(b) On 24 January 1986, the difference in heliocentric longitudes of Pioneer 11 and Voyager 2 (Uranus) is only 8° (about the same geocentrically).

(c) At the present time, clean TM signals are being received from Pioneer 11 at 64 b.p.s. by the 34-meter stations at a geocentric distance of 15 AU. Hence, it seems reasonable to expect that good data can be received at 32 b.p.s. in January 1986 (~ 20 AU).

8. Conclusion

I conclude that we should make every reasonable effort to obtain continuous 24-hour per day TM reception of Pioneer 11 with 34-meter DSN stations during at least the period 1 December 1985 -- 15 February 1986.

(Pioneer 11 is in conjunction on 3 December 1985 but is over 16° north of the ecliptic plane so that there is no problem with solar interference.)

APPENDIX I. References and Nomenclature

1. Basic ephemeris data have been extracted from the following sources:

(a) Astronomical Papers Prepared for the Use of the American Ephemeris and Nautical Almanac, Volume XII Coordinates of the Five Outer Planets 1653-2060, by W. J. Eckert, D. Brouwer, and G. M. Clemence, 1951 (U. S. Gov. Printing Office, Washington, DC).

(b) Jet Propulsion Laboratory/Ames Research Center Projected Ephemeris of Pioneer 11 1 January 1984 -- 1 July 1986 of August 1983.

(c) Jet Propulsion Laboratory Projected Ephemeris of Voyager 2.

(d) J. Meeus, Astronomical Tables of the Sun, Moon, and Planets, Willman-Bell, Inc. Richmond, VA, 1983.

2. All coordinates used in this memorandum are referenced to the heliocentric mean equinox/ecliptic 1950.0 coordinate system: X, Y, Z for rectangular coordinates and r, λ, β, θ for radial distance, longitude, latitude, and co-latitude, respectively. Distances are in astronomical units (1 AU = 1.495979×10^8 km).

3. Subscripts:

P = Pioneer 11

V = Voyager 2

U = Uranus

E = Earth

S = Sun

e.g., $\vec{r}_{SP}$ = radial vector from the sun to Pioneer 11.

APPENDIX II. Speculations on the Magnetosphere of Uranus

1. Magnetic Moment of Uranus

Current knowledge of the angular momenta and magnetic moments of the planets is summarized in Table A1 and plotted in Figure A1. The straight line in the figure is the unweighted least squares fit to the points for Mercury, Mars, Earth, Saturn, and Jupiter. The equation of this line is

$$\log M = -13.4\ (\pm\ 6.7) + 0.95\ (\pm\ 0.16) \log I\omega .$$

In Figure A1, the vertical lines labeled Uranus and Neptune represent empirically reasonable ranges for the magnetic moments of these two planets (at the approximately known values of $I\omega$).

The "nominal" value for Uranus is

$$M \approx 2.7 \times 10^{27} \text{ gauss cm}^3$$
$$\approx 0.18 \text{ gauss } R_U^3 .$$

2. Probable Existence of a Uranian Magnetosphere

The standoff distance r of the magnetopause on the sunward side of a planet having magnetic moment is given by the magnetohydrodynamic stagnation condition

$$n m v^2 = M^2/2\pi r^6$$

where n, m, and v are the number density, mass, and directed velocity of protons in the solar wind. At the orbit of Uranus, using the values

$$v = 400 \text{ km s}^{-1}$$

$$n = 0.014 \text{ cm}^{-3}$$

$$\frac{r}{r_U} = 1.64 \times 10^{-8} M^{1/3}$$

[Van Allen, J. A., On the magnetospheres of Jupiter, Saturn, and Uranus, Highlights of Astronomy, Vol. 4, Part I, 195-224, 1977].

For $M = 2.7 \times 10^{27}$ gauss cm^3

$$r = 23 r_U .$$

Within this radial distance from the center of the planet, it is reasonable to expect a well-developed magnetosphere, albeit

one of extraordinary properties because of the approximately axial alignment of the rotational axis with the planet-sun line in 1986 [Siscoe, G. L., Two magnetic tail models for Uranus, Planet. Space Sci., 19, 483-490, 1971].

Recent observations by the International Ultraviolet Explorer of auroral optical emissions from Uranus provide the only available direct evidence for the existence of a well-developed magnetosphere [Durrance, S. T., and H. W. Moos, Intense Ly α emission from Uranus, Nature, 299, 428-429, 1982] [Clarke, J. T., Detection of auroral hydrogen Lyman-Alpha emission from Uranus, Ap. J., 263, L105-L109, 1982] [Caldwell, J., R. Wagener, and T. Owen, Tentative confirmation of an aurora on Uranus, Nature, 303, 310-312, 1983].

ANGULAR MOMENTA AND MAGNETIC MOMENTS OF PLANETS

	$I\omega$	M	$\frac{M}{I\omega} \times 10^{15}$
	$g\ cm^2\ s^{-1}$	$gauss\ cm^3$	$gauss\ cm\ s\ g^{-1}$
Mercury	9.74 E 36	2.4 E 22	2.5
Venus	1.82 E 38	< 3 E 21	< 0.02
Earth	5.859 E 40	7.92 E 25	1.35
Mars	1.98 E 39	1.4 E 22	0.007
Jupiter	4.19 E 45	1.53 E 30	0.37
Saturn	7.03 E 44	4.32 E 28	0.061
Uranus	1.52 E 43	--	--
Neptune	2.07 E 43	--	--
Pluto	~ 3 E 36	--	--
Moon	2.36 E 36	< 4 E 20	< 0.2

Note: $a\ E\ b = a \times 10^b$

4/17/84

Table A1

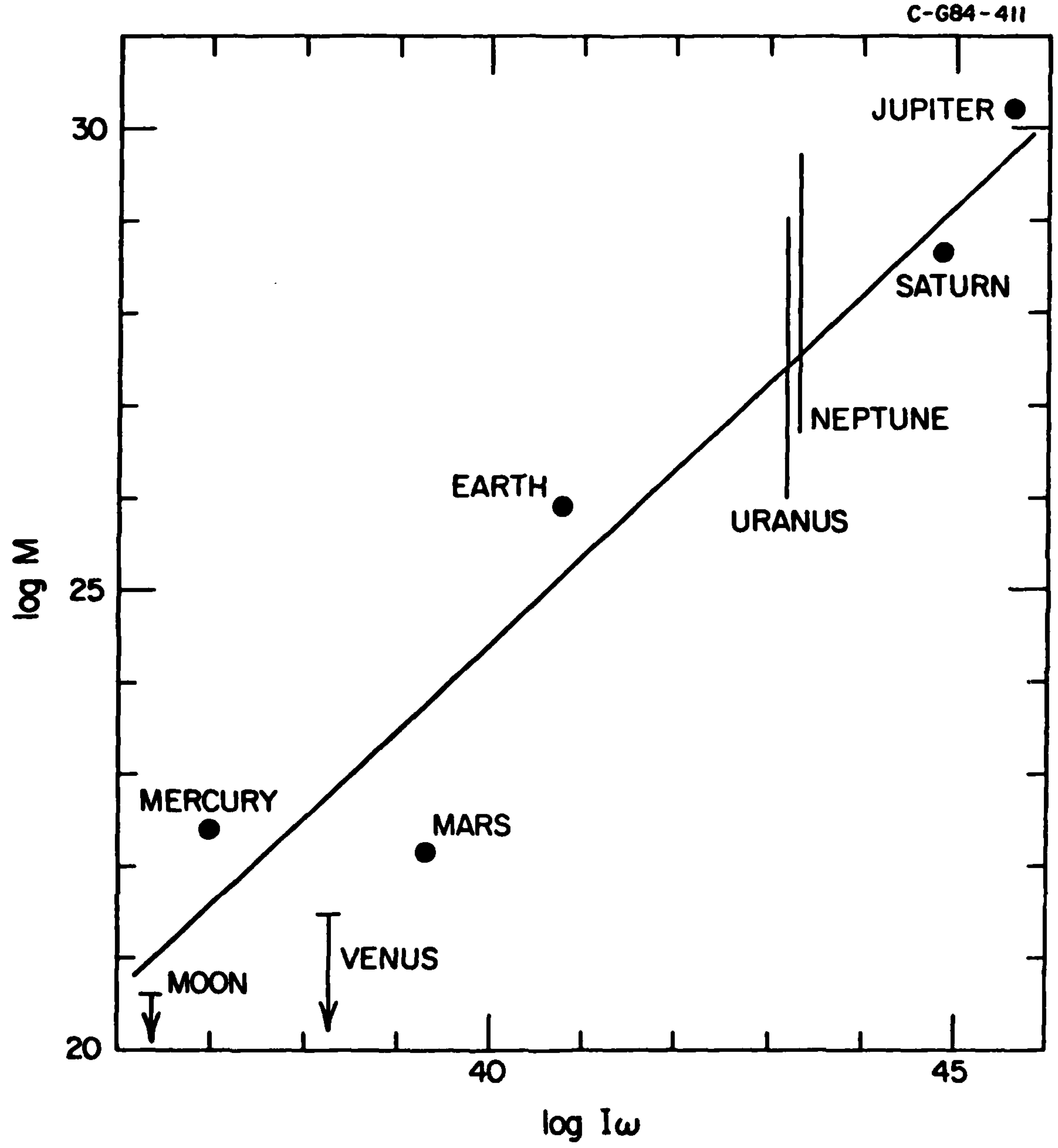
C-G84-411
JUPITER
SATURN
NEPTUNE
URANUS
EARTH
MERCURY
MARS
VENUS
MOON
30
25
20
40
45
log M
log Iω

Figure A1

END

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